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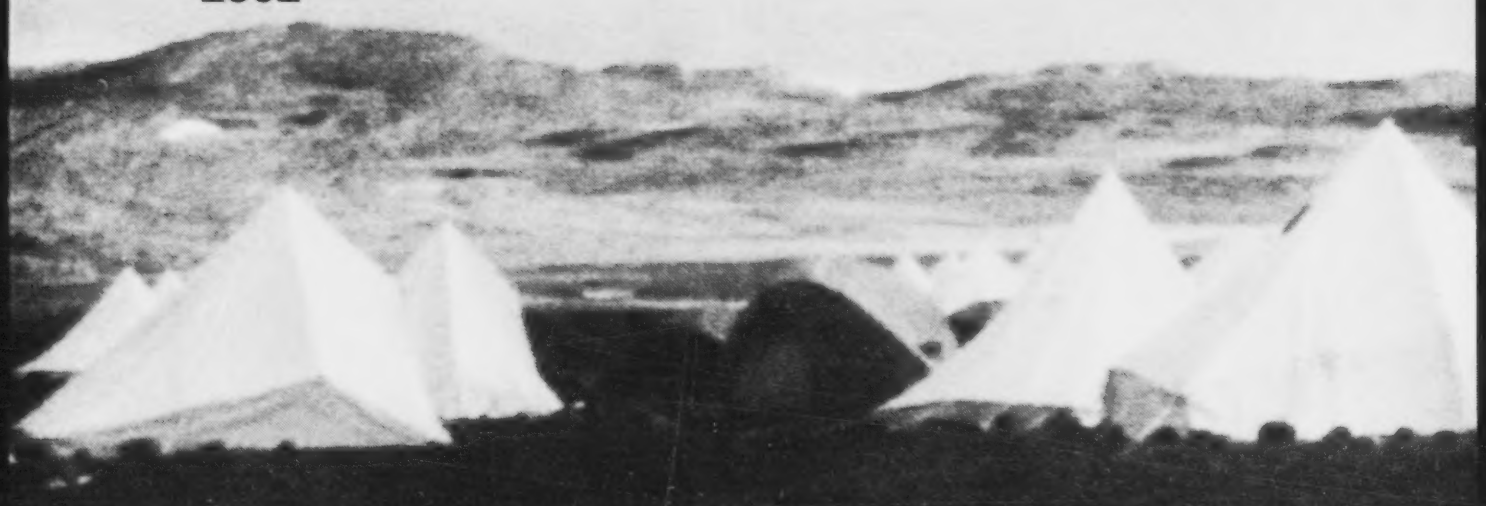

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Hierarchical classification of tectonic assemblages for use with thematic, computer-based query systems: a preliminary scheme

L.C. Struik and M.B. Quat

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Abstract: A hierarchical system of classification for tectonic assemblages is introduced to permit thematic querying of bedrock geological databases. Such a hierarchical scheme permits query capture of specific and general tectonic environments. The classification hierarchy is based on the premise that all rock formations formed in a tectonic environment stem from a single lineage, formation of the universe. We deal solely with the segment of the lineage on Earth, because of our present preoccupation with geological mapping on Earth. Tectonic assemblages formed on Earth are classified by plate tectonic theory and extraterrestrial impacts. The scheme is extensible, although its evolution for the Earth-based component is restricted by use of plate tectonic genetic concepts.

Résumé : On a mis au point un système de classification hiérarchique des assemblages tectoniques afin de pouvoir effectuer des recherches thématiques dans des bases de données géologiques sur le substratum rocheux. Un tel système permet de faire des recherches dans des milieux tectoniques tant précis que généraux. La hiérarchie repose sur le fait que toutes les formations rocheuses d'un milieu tectonique découlent d'une lignée unique, soit la formation de l'univers. Nous traitons exclusivement du segment Terre, car nous dressons présentement des cartes géologiques de la Terre. Les assemblages tectoniques qui se sont formés sur Terre sont classés d'après la théorie des plaques tectoniques et des impacts météoritiques. La classification est extensible, bien qu'on limite l'évolution de la composante basée sur la Terre en appliquant les concepts génétiques de la tectonique des plaques.

INTRODUCTION

We describe a scheme for classification of lithological assemblages formed in tectonic environments (tectonic assemblages) that is designed for use with geological map databases, particularly the North American Data Model (NADM) (B.R. Johnson, B. Brodarick, G.L. Raines, J. Hastings, and R. Wahl, *Digital Geologic Map Data Model version 4.3*, available at http://geology.usgs.gov/dm/model/Model43a.pdf, accessed July 2002). The NADM is a geological database model under joint North American design that is to be used for standardized query access to geological maps. The classification scheme for tectonic assemblages was created for use with the prototype Canadian digital bedrock geology map dataset being prepared for the Canadian Geoscience Knowledge Network (CGKN) (P.H. Davenport, J.M. Journeay, E. Boisvert, and S.P. Colman-Sadd, unpub. proj. prop., 2000; J. Broome, E. Grunsky, and J. Rupert, unpub. proj. prop., 2001; Struik et al., 2002). The CGKN is under design as a fully integrated, Internet-accessible geological database for Canada, whose data is derived from partner agencies throughout Canada (currently provincial, territorial, and federal governments). For the future complete CGKN digital bedrock geology map of Canada, the classification scheme must accommodate the diversity of tectonic assemblages present in existing and future map legends, and permit the generation of thematic maps based on tectonic assemblages.

Classifications for thematically based computer queries of geological databases are most useful in a hierarchical structure (Gillespie and Styles, 1999; Struik et al., 2002). Examples of the use and efficacy of such hierarchical classifications have been documented for rock names (Struik et al., 2002), and are inherent to geological time scales (A.V. Okulitch, pers. comm., 2001). An example of a hierarchical structure is the family tree, and in this discussion, the analogy with human lineages will be used to describe the relationships between the various orders of the hierarchy (e.g. parent-child).

In the case of lithological assemblages formed in tectonic environments, the idea is to link specific tectonic assemblages to parent tectonic assemblages so that database queries can capture the specific or large families of specific assemblages for display in GIS systems. For instance, a query could be done to locate all rock units formed as shelf reefs or capture those same units and their siblings and parents with a query to locate all units formed at continental margins. As the scheme presented here is preliminary, its most detailed subdivisions have not been displayed.

This classification system is meant to capture the genetic heritage of rock suites. As such it must work with existing genetic theory, the details of which are generally controversial and the whole of which could be challenged. The classification system therefore is date-sensitive and not unique. It is meant to reflect our current understanding and thereby permit the generation of thematic maps that reflect and allow reflection on that understanding.

Here we classify only tectonic geological processes on Earth, some of which are applicable to other parts of the universe. We do not analyze and classify components of the universal theory of tectonic geological processes (e.g. nebular theories, jovian versus terrestrial planets). Instead, we concentrate on Earth-based tectonics that we find reflected in geological maps of Earth. This classification system uses plate tectonics (a widely accepted, all-encompassing theory) as its basis for Earth-based geology. The system is extensible and genetic concepts of the geological processes of space and celestial bodies can be added when warranted.

TECTONIC ASSEMBLAGE CLASSIFICATION SYSTEM

The proposed system (Fig. 1) classifies the genesis of rock and rock unit assemblages. As such, it is a classification system applied to geological units (e.g. members, formations, suites) and not to individual rock types. Tectonic environments (i.e. places where geological materials are being deformed or moved relative to each other) are interpreted to produce unique assemblages of rocks, called 'tectonic assemblages' in the Canadian Cordillera (Tipper et al., 1981; Wheeler and McFeely, 1991). This system classifies tectonic assemblages and, by corollary, related tectonic environments.

The tectonic assemblage classification system consists of a single hierarchy whose primary ancestor is the universe, because all assemblages were formed as part of the tectonic geological processes of the universe. Here we are concerned solely with those assemblages and tectonic processes on Earth, i.e. assemblages that represent just a branch or two of those in the universe. Our primary concern is the generation of a bedrock geology map database that can be applied to geological maps in Canada and North America. We use two branches of tectonic assemblages for Earth, those derived from plate tectonic processes and those derived from the interaction of Earth with objects from space (extraterrestrial). This general schema is typically followed in geology text books, where the opening chapters are on Earth's place in the universe and particularly in the solar system, followed by details of the general theory of geology on Earth (e.g. Matthews, 1982; Skinner and Porter, 2000).

Extraterrestrially formed assemblages are confined to impacts of objects from space that form craters and associated ejecta. Components of the craters and ejecta blankets could be subdivided, although that has not been done here.

The Earth-formed assemblages are divided by elements of plate tectonic theory. In the context of this paper, plate tectonic theory explains geological processes on the Earth's surface to be a consequence of the interaction between slab-like segments of the Earth composed of a felsic crust and an ultramafic mantle (plates). The plates move in different directions relative to each other, driven by the force of gravity and thermal regimes. These plates have internal coherence to depths of 100 km (lithosphere), and move relative to a solid Earth's

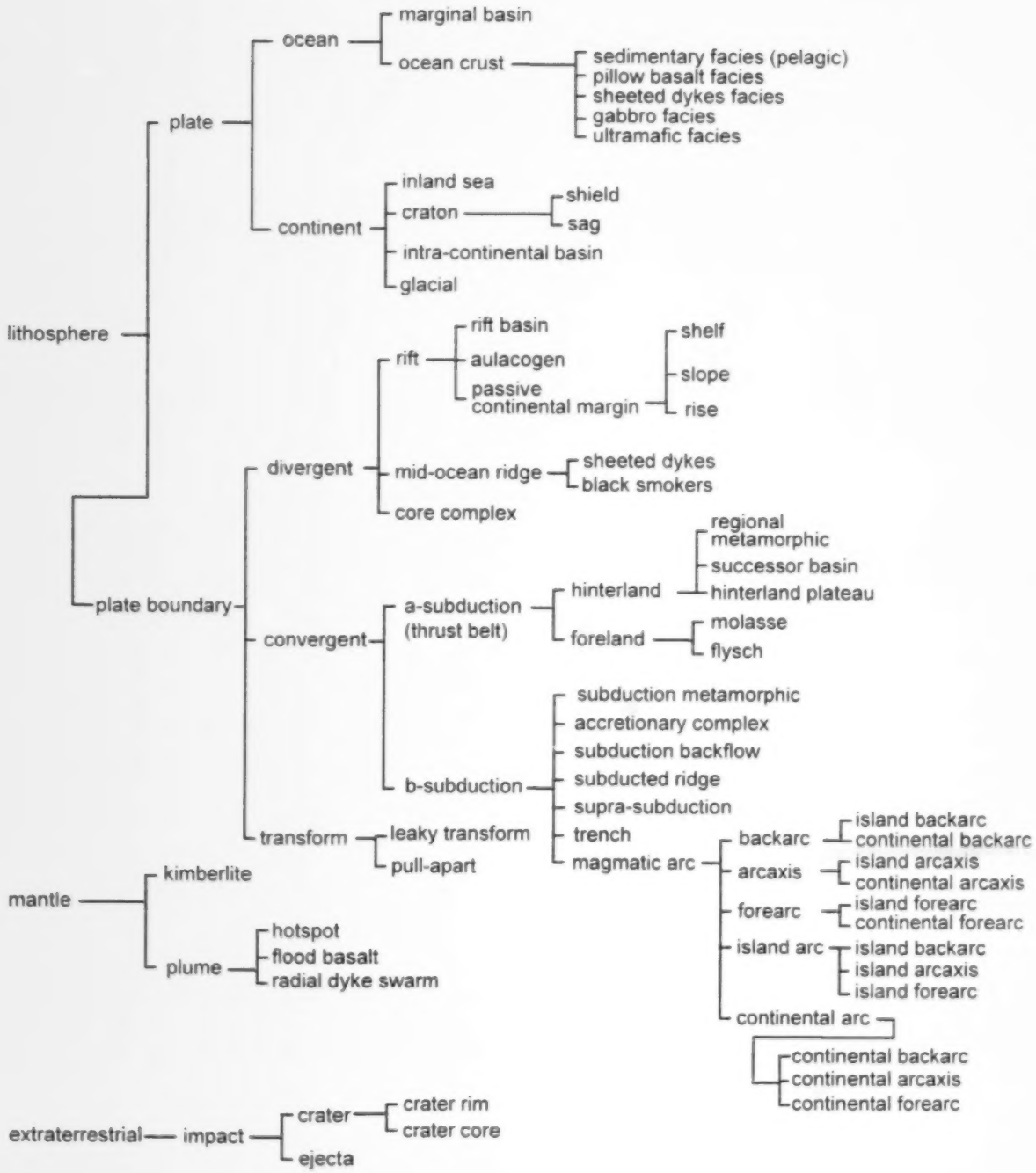

Figure 1. *Hierarchical classification of tectonic assemblages (rock suites associated with distinct tectonic environments).*

core over an incoherent mobile thermally convecting mantle (asthenosphere). The motions of the lithosphere and asthenosphere cause all Earth-based tectonics.

Geological maps of the Earth's surface and near surface portray assemblages formed from two primary manifestations of plate tectonics, i.e. 1) dynamic interaction of the plates and 2) processes active in the deep mantle. To highlight this concept, Earth-formed assemblages are subdivided into those formed as part of the lithosphere and those formed from the mantle. The distinction between lithospheric and asthenospheric mantle is left intentionally vague because rock assemblages generated from mantle processes do not always respect our notion of the lithosphere–asthenosphere boundary.

Lithosphere

Tectonic assemblages formed by lithospheric activity are subdivided into those formed on and within plates, and to those formed at plate boundaries. Plate-formed assemblages are in turn subdivided as continental versus oceanic. Assemblages formed on oceanic plates represent a mixture of environments formed by various processes, some of which we recognize in present-day oceanic plates and others we interpret from exposures of obducted oceanic terranes (ophiolite). Each of these is in turn subdivided into more specific tectonic assemblages.

The division of ophiolite into its subcomponents is problematic as the components are named after their dominant rock types. To avoid confusion, the term 'facies' is added after the subcomponent name (e.g. gabbro facies).

Tectonic assemblages formed at plate boundaries are subdivided into the three classic plate tectonic boundary types: divergence, convergence, and translation. Some difficulty arises in the classification system when assigning tectonic assemblages to plate boundary zones as opposed to intraplate environments. For instance, oceanic plates were formed from divergence processes and yet have developed intraplate tectonic environments after generation by divergence. In making assignments, the process that created the plate or part of a plate is considered to be distinct from younger tectonics that may have acted on that plate. For instance, ocean lithosphere assemblages formed in a complex suite of processes both at a plate boundary and during the life of the plate. Here we lump them together to represent an intraplate tectonic assemblage. This assemblage can be thrust (obducted) onto continental plates at convergent boundaries; however, they do not create a new rock suite by the process of obduction and so are not assigned to convergent plate boundaries (contraction).

Convergence is subdivided into a- and b-subduction, whereby a-subduction is the imbrication of continental and oceanic crust and b-subduction is the process of Benioff subduction by which oceanic plates sink into the mantle.

Metamorphic complexes are problematic because geologists interpret both genesis of the protolith and genesis of the metamorphism. Here we classify these complexes primarily by the tectonic process that generated them. For example, granulite belts and regional high-grade belts formed by overthickening of the crust and subsequent uplift are classed as part of a-subduction (regional metamorphic belts: Miyashiro, 1973), although Miyashiro (1973) questioned whether continental collision could generate metamorphic belts. He suggested a tripartite classification of metamorphic belts: 1) continental arcs, 2) ocean island arcs, and 3) 'reversed' island arcs (subducting oceanic marginal-basin plates). At this stage in development of the classification, we show these three concepts as b-subduction-generated metamorphism under the parent assemblage b-subduction.

Metamorphic suites within the classification can be crosslinked so that they would also be returned using a query based on protolith genesis. For example, metamorphosed accretionary complexes would be displayed by a query for a- or b-subduction assemblages.

To make possible such a query on metamorphic characteristics or protolith assemblage, each assemblage must be assigned both metamorphic and protolith assemblage classifications. Uncertainties with respect to theory, interpretation, and information abound in geology, and such classification assignments are rarely easy to do and their use may be questioned. It is recommended to try however. Just as it has been very enlightening to build such a classification system to test conventional usage of terms and ideas, it will be very enlightening to assign rock units to this genetic classification scheme to test geological understanding.

Mantle

Mantle-formed tectonic assemblages are those generated within the mantle and manifested at the Earth's surface. Examples of these include kimberlite and plumes. Plume assemblages are subdivided into hot spots, flood basalt, and radial dyke swarms that are surface-mappable manifestations of the plumes. Depending on the definition of hot spot and plume, they are either unique manifestations of mantle upwelling and therefore siblings in the classification system, or all mantle upwellings are plumes and a hot spot is a unique type of plume and therefore they have a parent-child relationship. Each of these mantle type assemblages has different manifestations depending on whether they were formed through and on oceanic or continental crust.

DISCUSSION AND CONCLUSIONS

The hierarchical tectonic assemblage classification scheme proposed here is an attempt to create a thematically consistent means to allow queries of geological units in a bedrock geology database. The use of hierarchical classification schemes means that each tectonic assemblage can be categorized as generally or as specifically as the author's description allows. Because the most detailed levels (children) in the database are related to all the higher levels (parents) in the branch, a query such as "select all tectonic assemblages formed by divergence" will not only select assemblages indexed at that level (Fig. 1), but also all children of that

branch (rift, transform, core complex, aulacogen, and their children). Similarly, if the tectonic genesis of the assemblage is poorly understood, it may be classified only at the higher levels. As the tectonic assemblages come from an analysis of map-unit descriptions, ultimately these queries can be made to return map units and thus produce a map of the query results: a customized thematic geological map.

A special search scenario has been established for components of magmatic arcs to accommodate the situation whereby it is understood which component of the arc the assemblage comes from, but not whether the assemblage was an island or continental arc. Searching for back-arc assemblages with unknown island or continental affinity, for instance, will also return island or continental back-arc assemblages.

The scheme is extensible, as it permits the addition of new classification subtrees to accommodate more map information or to allow additional ways to query the information. Continued refinement will be necessary as we gain experience in building and using the map database. Full definitions of the terms will be necessary to clarify the nature of the tectonic assemblages.

Mineral deposits and mineral deposit types are commonly associated by their genesis to tectonic environments. It would be productive to link this type of environmental assemblage tree to the hierarchical classification of ore deposits, and some of this type of work is underway (C. Smyth, pers. comm., 2001; GeoReference Online Ltd, *MineMatch*™, available at http://www.georeferenceonline.com/MineMatch/index.htm, accessed July 2002). For example, a query for volcanic massive-sulphide deposit environments could return all units with back-arc tectonic assemblages.

The application of the tectonic assemblage classification system to digital geological maps requires that each geological unit be assigned a tectonic assemblage classification. That classification has to use the standard terms in a tectonic assemblage classification system. Doing so creates a powerful tool for generating thematic maps based on genetic characteristics, useful for analyzing geology and discovering relationships.

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